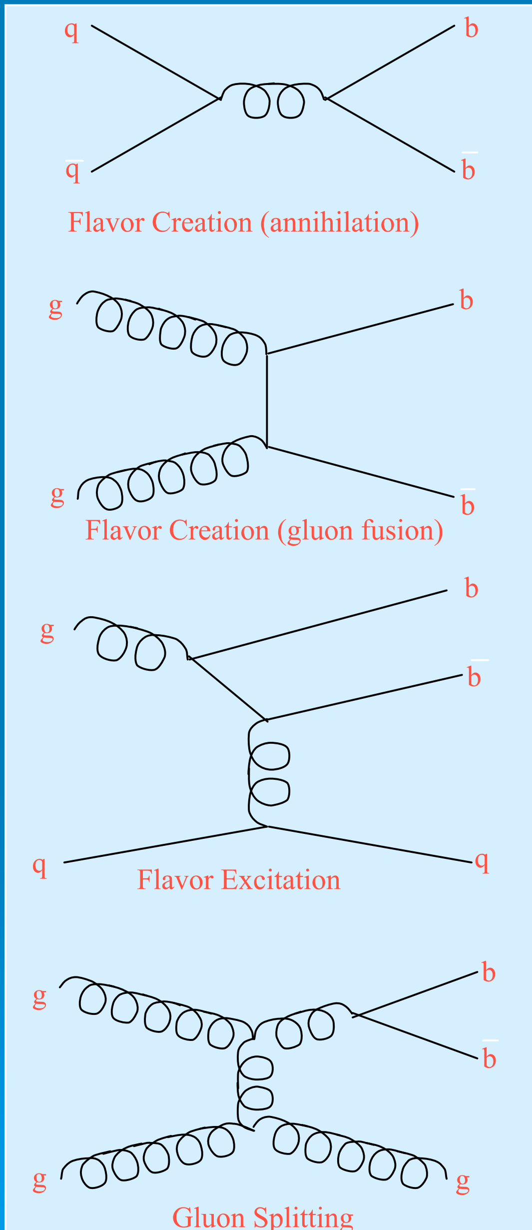
Measurement of the Masses and Lifetimes of B Hadrons at the Tevatron

Pierluigi Catastini
Universita' di Siena - I.N.F.N. Pisa

Heavy Flavor Physics In Hadronic Environment



b's produced via strong interaction

decay via weak interaction

Tevatron is great for heavy flavor:

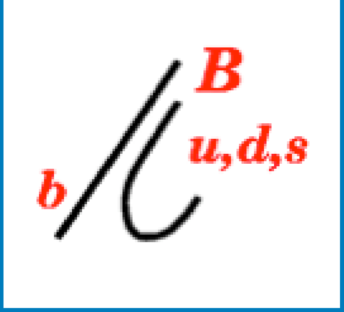
- Enormous *b* production cross-section, x1000 times larger than e^+e^- B factories
- All B species are produced (B^0, B^+, Λ_b, B_s, etc...)

However,

- Inelastic (QCD) background is about x1000 larger than b cross-section
- Online triggering and reconstruction is a challenge: collision rate ~1MHz → tape writing limit ~100Hz

Heavy Flavor Production Fractions

Rate of b quark fragmentation with other quarks to form B Mesons and baryons:



- B* and B** contribution not disentangled
- B^0, B^+, B_s and $\Lambda_b \rightarrow f_d$, f_u, f_s and $f_{\Lambda b}$
- Measure relative fractions f_u/f_d , $f_s/(f_u+f_d)$, $f_{\Lambda b}/(f_u+f_d)$

Using semileptonic B and Λ_b decays we measure:

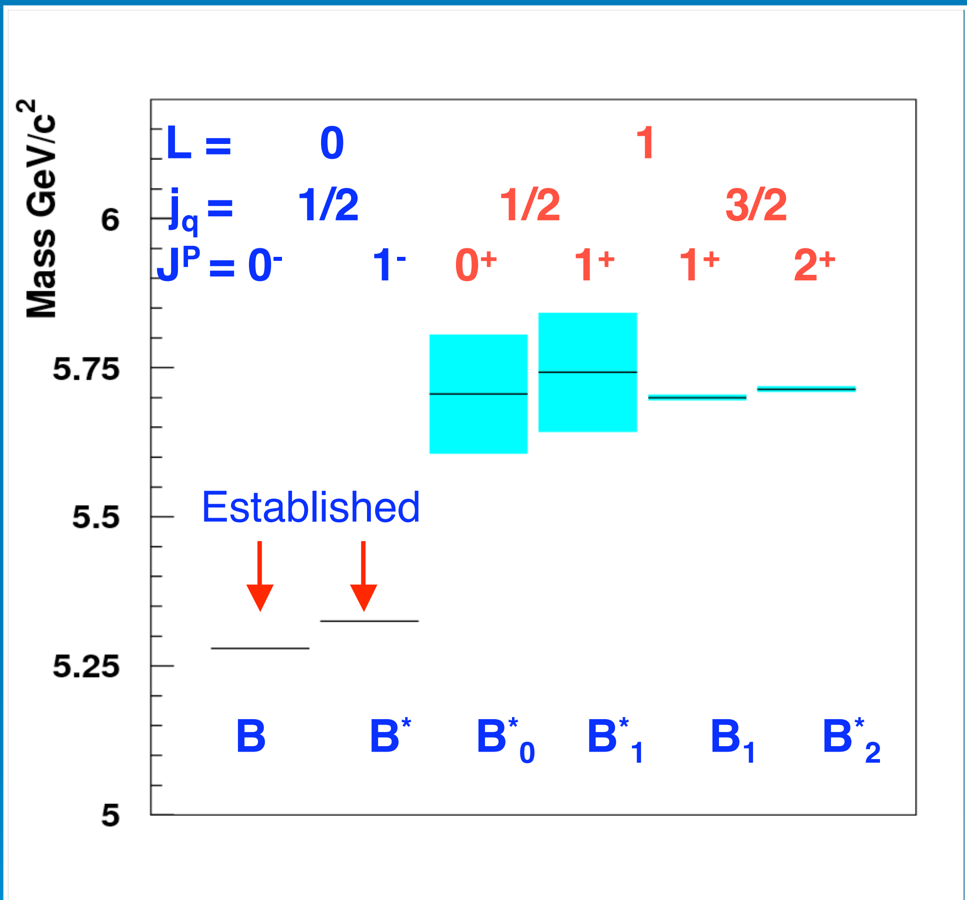
$$
\begin{aligned}
\frac{f_s}{f_u+f_d} \times \mathcal{BR}(D_s^+ \to \phi\pi^+) &= (5.76 \pm 0.18(stat)^{+0.45}_{-0.42}(sys)) \times 10^{-3} \\
\frac{f_{\Lambda_b}}{f_u+f_d} \times \mathcal{BR}(\Lambda_c^+ \to pK^-\pi^+) &= (14.1 \pm 0.6(stat)^{+5.3}_{-4.4}(sys)) \times 10^{-3} \\
\frac{f_{\Lambda_b}}{f_u+f_d} \times \mathcal{BR}(\Lambda_b^0 \to \ell\nu\Lambda_c^+)\mathcal{BR}(\Lambda_c^+ \to pK^-\pi^+) &= (12.9 \pm 0.6(stat) \pm 3.4(sys)) \times 10^{-4}
\end{aligned}
$$

CDF (360pb^{-1}):

$$
\begin{aligned}
\frac{f_u}{f_d} &= 1.054 \pm 0.018(stat)^{+0.025}_{-0.045}(sys) \pm 0.082(\mathcal{BR}) \\
\frac{f_s}{f_u+f_d} &= 0.160 \pm 0.005(stat)^{+0.011}_{-0.010}(sys)^{+0.057}_{-0.034}(\mathcal{BR}) \\
\frac{f_{\Lambda_b}}{f_u+f_d} &= 0.281 \pm 0.012(stat)^{+0.058}_{-0.056}(sys)^{+0.128}_{-0.086}(\mathcal{BR}).
\end{aligned}
$$

$f_{\Lambda b}$ differs from LEP by ~2.2 σ

Excited B-Mesons: Theory



Prediction of masses from M. Di Pierro, E.Eichten, *Phys.Rev. D64:114004, 2001*

Good qualitative understanding

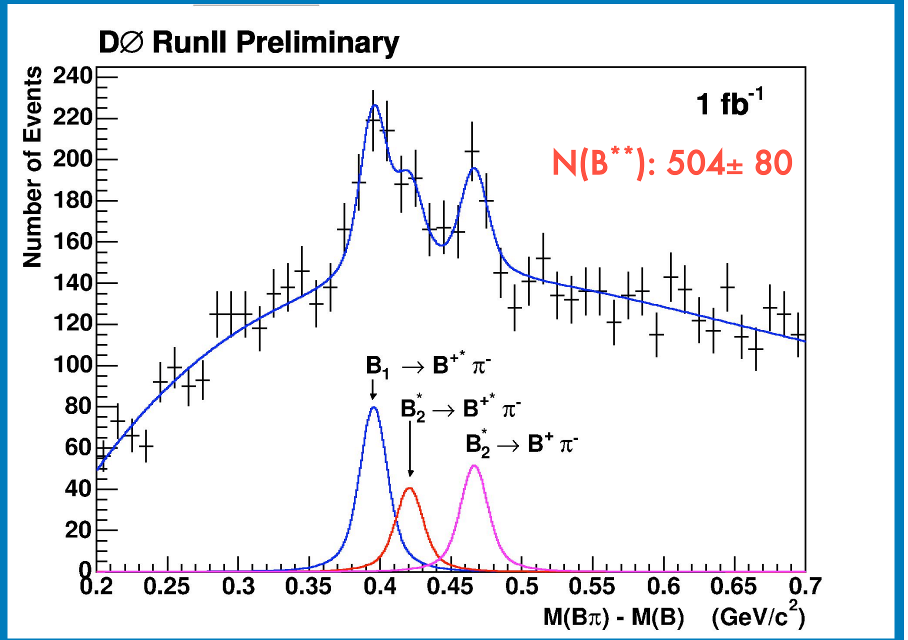
- 4 *P*-states: B^*_0, B^*_1, B_1, B^*_2
- B^*_0, B^*_1 decay through S-wave
  They are very wide (~100MeV).
- B_1, B^*_2 decay through D-wave and should be narrow (~10 MeV).
- B^*_2 can decay to $B^*\pi$ and $B\pi$;
- B_1 can decay *only* to $B^*\pi$;

Less good quantitative description

- Prediction of masses, widths and decay properties is less precise.

Excited B-Mesons

- Starting from a sample of
  ~16k $B+ \rightarrow J/\psi K+$
- Look for a Pion
- Evaluate the difference $M(B\pi) - M(B)$
  (better resolution ~9MeV/c²)
- γ from B* decays is not reconstructed
  (this explains the two peaks from B_2^*)



Masses and widths

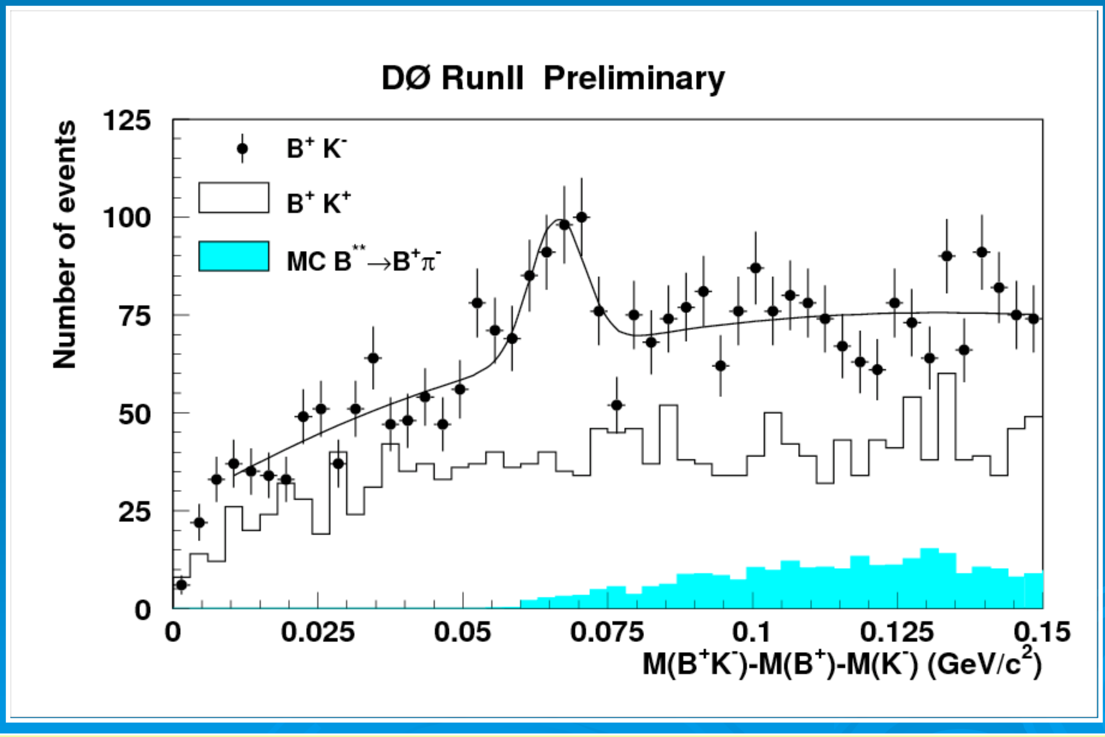
$$M(B_1) = 5720.8 \pm 2.5\ (stat) \pm 5.3\ (syst)\ \ MeV/c^2$$
$$M(B_2^*) - M(B_1) = 25.2 \pm 3.0\ (stat) \pm 1.1 (syst)\ MeV/c^2$$
$$\Gamma(B_1) \equiv \Gamma(B_2^*) = 6.6 \pm 5.3\ (stat) \pm 4.2\ (syst)\ \ MeV/c^2$$

Production and Decay (D0 1 fb⁻¹)

$$\frac{Br(b \rightarrow B_J \rightarrow B^{(*)}\pi)}{Br(b \rightarrow B^{\pm})} = 0.16 \pm 0.024\ (stat) \pm 0.028\ (syst)$$
$$\frac{Br(B_1 \rightarrow B^{*}\pi)}{Br(B_J \rightarrow B^{(*)}\pi)} = 0.545 \pm 0.064\ (stat) \pm 0.071\ (syst)$$
$$\frac{Br(B_2^* \rightarrow B^{*}\pi)}{Br(B_2^* \rightarrow B^{(*)}\pi)} = 0.513 \pm 0.092\ (stat) \pm 0.115\ (syst)$$

First Direct Observation of B_{s2}^{*0} Meson

- (bs) system is expected to have a similar pattern of *P*-states, as for (bd) and (bu)
- B_{sJ} decay to $B^{(*)}K$ *($Bs^{**} \rightarrow Bs\pi$ suppressed due Isospin conservation).*
- Same $B+ \rightarrow J/\psi K+$ sample
- Looking for a Kaon instead of a π *(Assign the Kaon mass to the additional track)*
- Signal can be interpreted as $B_{s2}^{*0} \rightarrow BK$ (*Significance* $>5\sigma$)



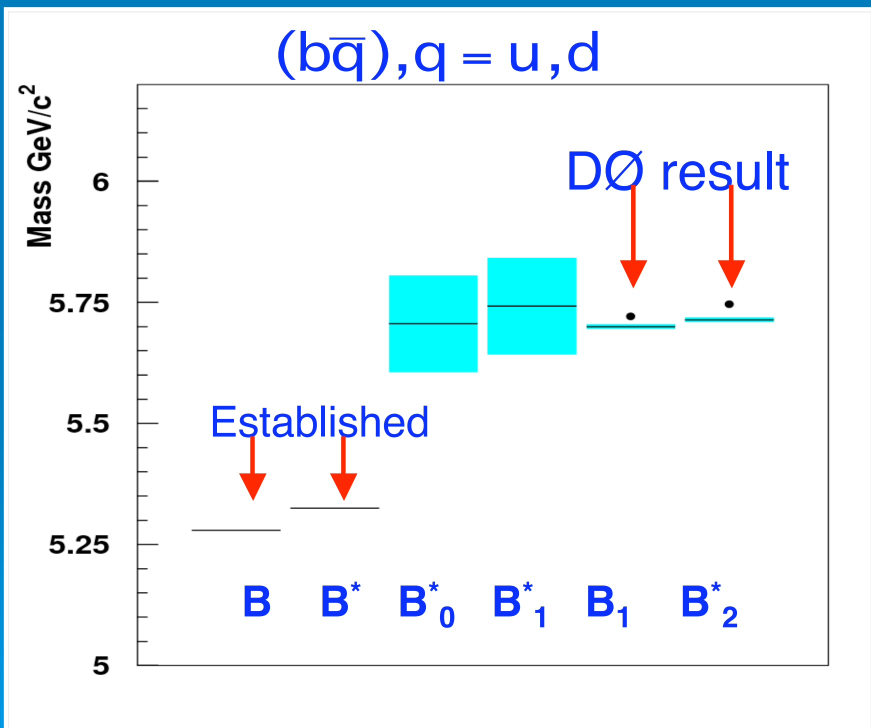
(D0 1 fb^{-1})

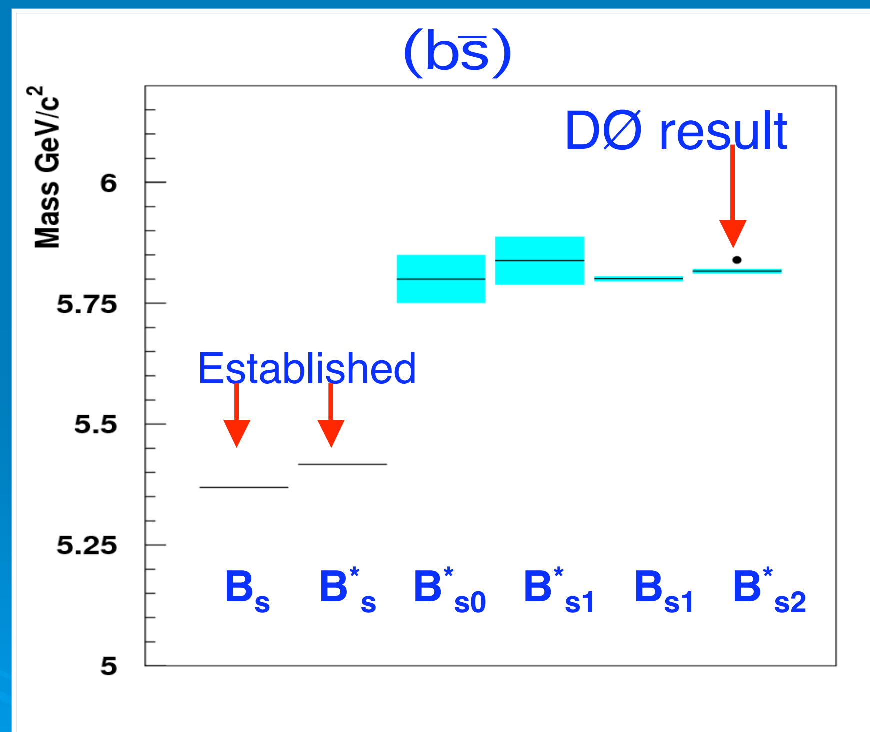
$M(B_{s2}^{*0}) = 5839.1 \pm 1.4\ (stat) \pm 1.5\ (syst)\ \ MeV/c^2$

Excited B: Comparison to the Theory

Theory predicts same mass splitting for (bs) and (bd/u); interpreting this measurement as $M(B_{s2}^{*0})$ and combining with the $M(B_2^*)$ - $M(B_1)$ result:

- $B_{s2}^{*0} \rightarrow B^*K$ *suppressed* by phase space *(no signal around 0.025 GeV/c^2)*
- $B_{s1}^{0} \rightarrow B^*K$ is *under* B_{s1} mass threshold (*$M(B_{s1}^0)$-$M(B^*)$-$M(K)$ = - 4.9 ± 3.1 GeV /c^2*)



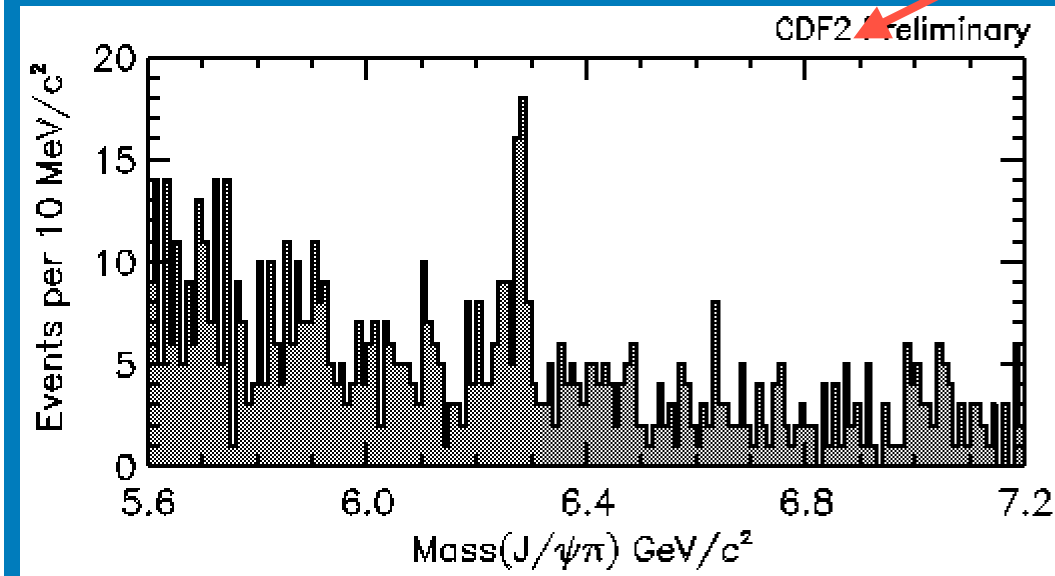


Prediction of masses from M. Di Pierro, E.Eichten, *Phys.Rev. D64:114004, 2001*

B_c Mass Measurement

(CDF 0.8 fb^{-1})

Done blind

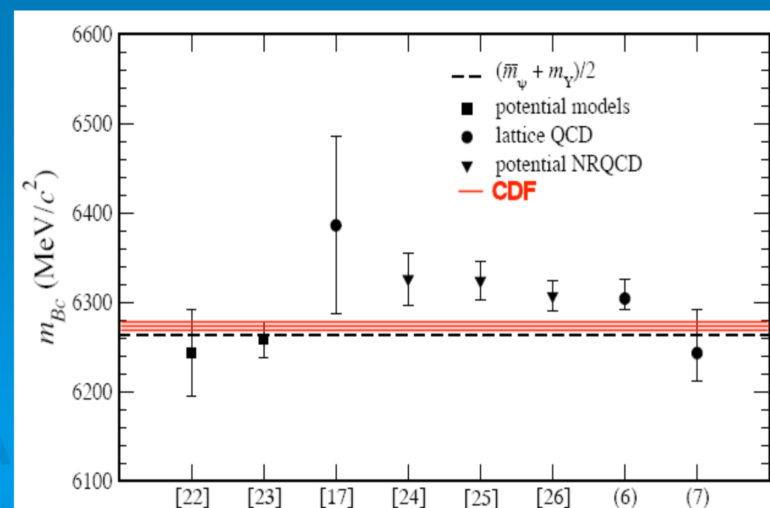


Fully reconstructed decay:

$B_c \rightarrow J/\psi\ \pi$

Significance > 6σ
over search area

Compared to lattice calculation that agreed with data elsewhere

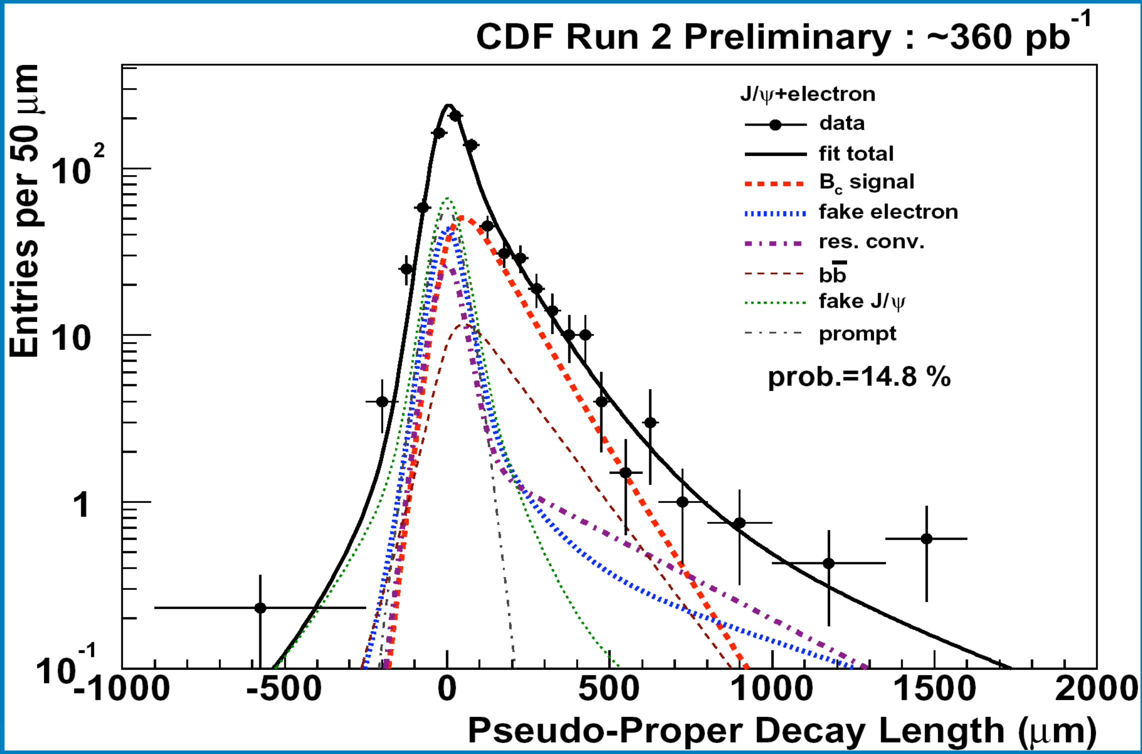


Mass(Bc) = 6275.2 +/- 4.3 +/- 2.3 MeV/c^2

Most precise measurement of Bc mass

B_c Lifetime Measurement

- Bc lifetime extracted from $B_c \rightarrow J/\psi e\nu X$ sample



- More stat than hadronic mode
- But also more background too

- B_c lifetime measured with J/ψ+e channel

0.474 +0.074/-0.066 ±0.033 ps

(CDF: Best in the world)

- Theoretical prediction: 0.55 ± 0.15 ps

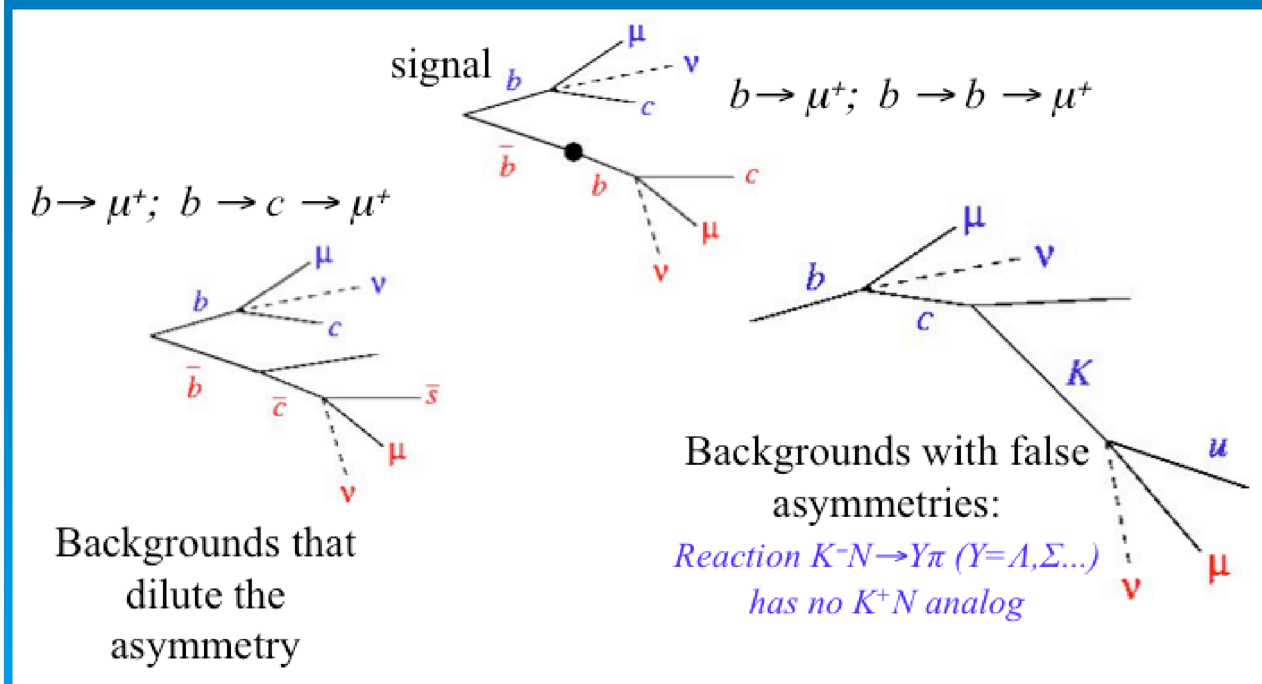
V. Kiselev, hep-ph/0308214

CP-violation parameter of B^0 mixing and decay

$$\frac{\mathrm{Re}(\varepsilon_{B^0})}{1+|\varepsilon_{B^0}|^2} = \frac{A_{SL}}{4}$$

Goal is to measure ε_b with part per mil precision by looking for asymmetry in like-sign dimuons:

$$A_{SL} = \frac{N(b\bar{b} \to \mu^+\mu^+X) - N(b\bar{b} \to \mu^-\mu^-X)}{N(b\bar{b} \to \mu^+\mu^+X) + N(b\bar{b} \to \mu^-\mu^-X)}$$



- First measure the raw Asymmetry correcting for detector effects
- Then extract the contribution from B decays: f_b

$$A_{SL} = f_b * A_{RAW}$$

CP-violation parameter : results

Using 970 pb^{-1} of data,

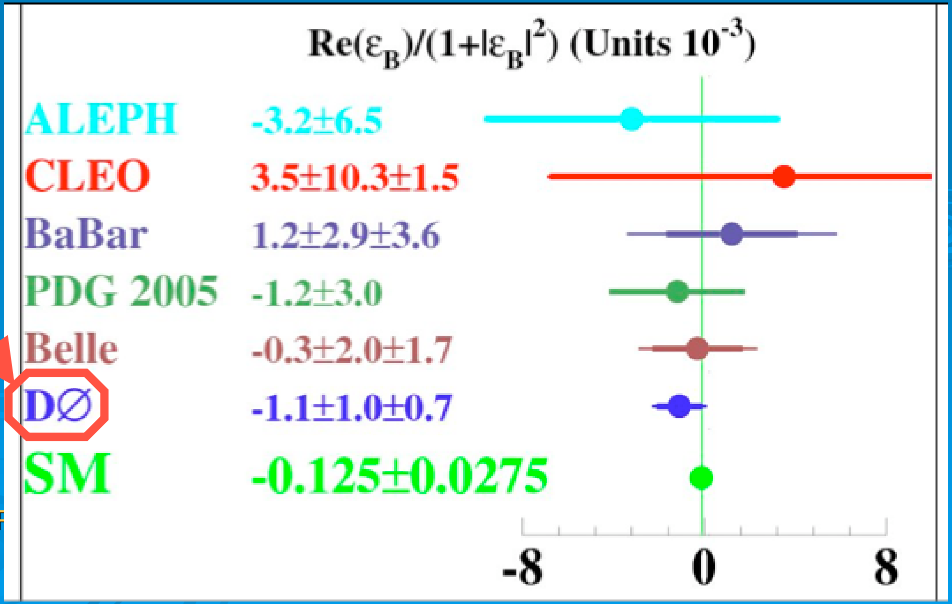
Cross-Check:
extract χ

$$\chi(D0) = 0.136 \pm 0.001 \pm 0.024$$
$$\chi(PDG) = 0.1281 \pm 0.0076$$

$$A_{SL} = -0.0044 \pm 0.0040\ (\mathrm{stat}) \pm 0.0028\ (\mathrm{syst})$$

$$\frac{\mathrm{Re}(\varepsilon_{B^0})}{1+|\varepsilon_{B^0}|^2} = \frac{A_{SL}}{4} = -0.0011 \pm 0.0010\ (\mathrm{stat}) \pm 0.0007\ (\mathrm{syst})$$

- Currently world best measurement
- Agrees with other results and SM expectation

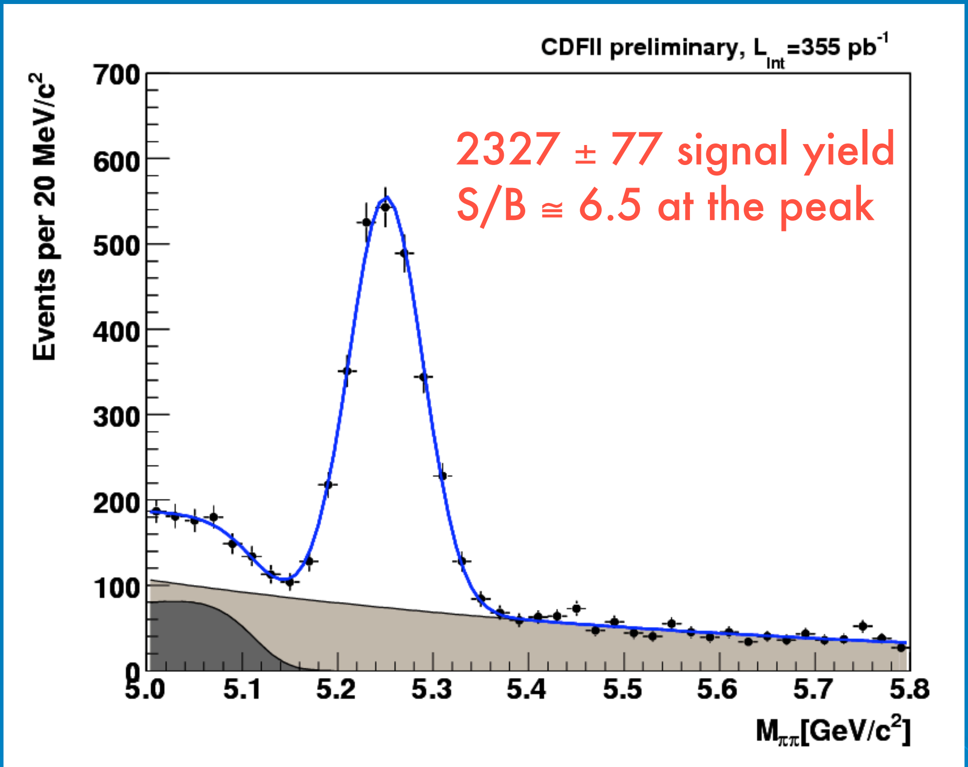


Composition of $B \to h^+h^{-\prime}$

The Peak is a mixture of several contributions:

- $B_d \to \pi\pi$
- $B_d \to \pi K$
- $B_s \to KK$
- $B_s \to K\pi$

($\pi\pi$ hypothesis)



Need to separate each contribution exploiting:

- *Kinematics*
- *Particle Identification information (dE/dx)*

Separate on statistical basis

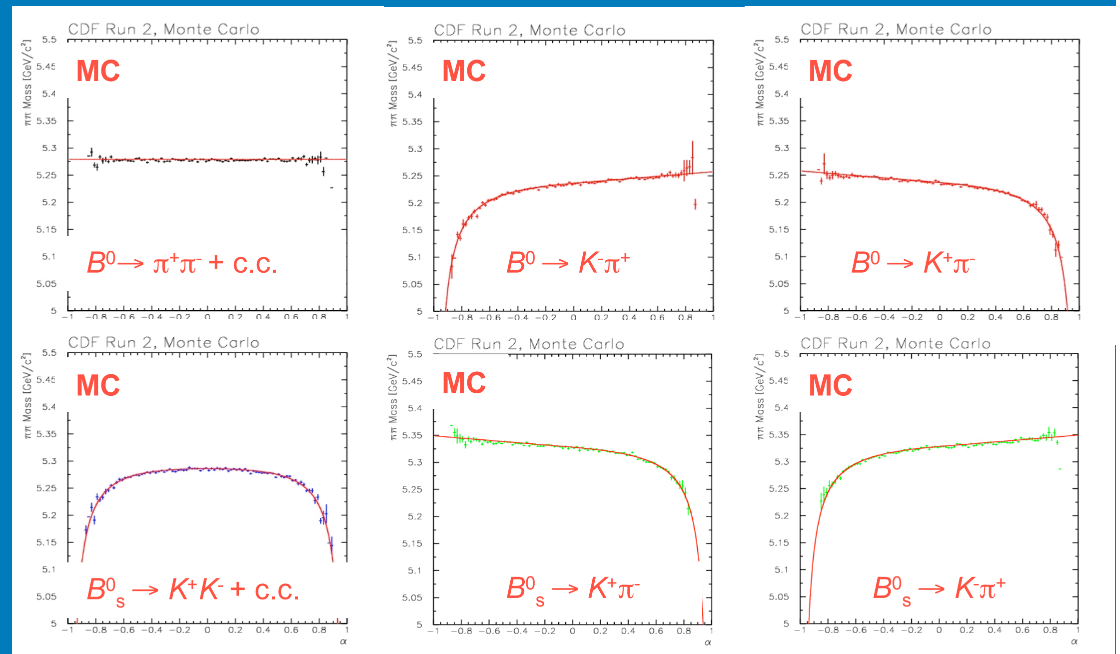
Multi - Dim Unbinned Likelihood Fit

Kinematics discrimination:

$\pi\pi$-mass vs signed momentum imbalance:

$(1 - p_{min}/p_{max})q_{min}$

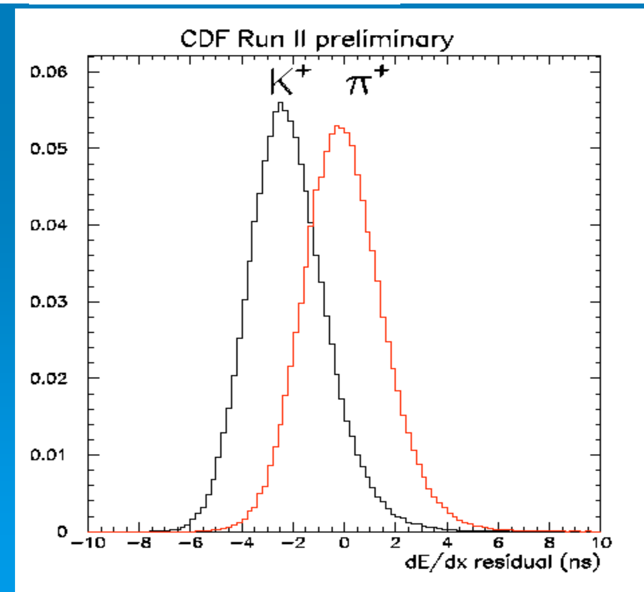
discriminates modes (and flavors in $K\pi$ modes).



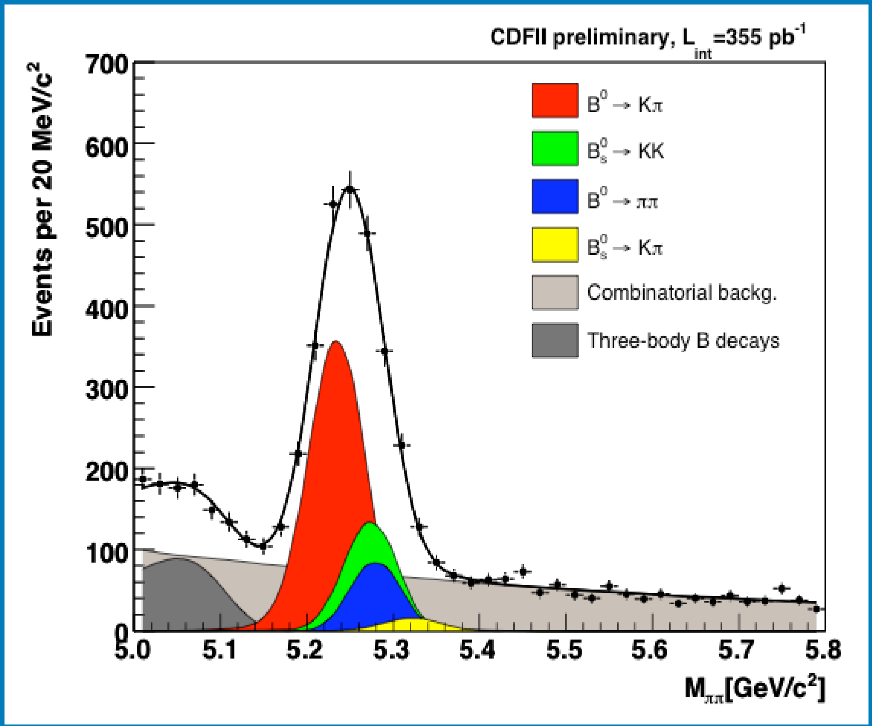
dE/dx discrimination:

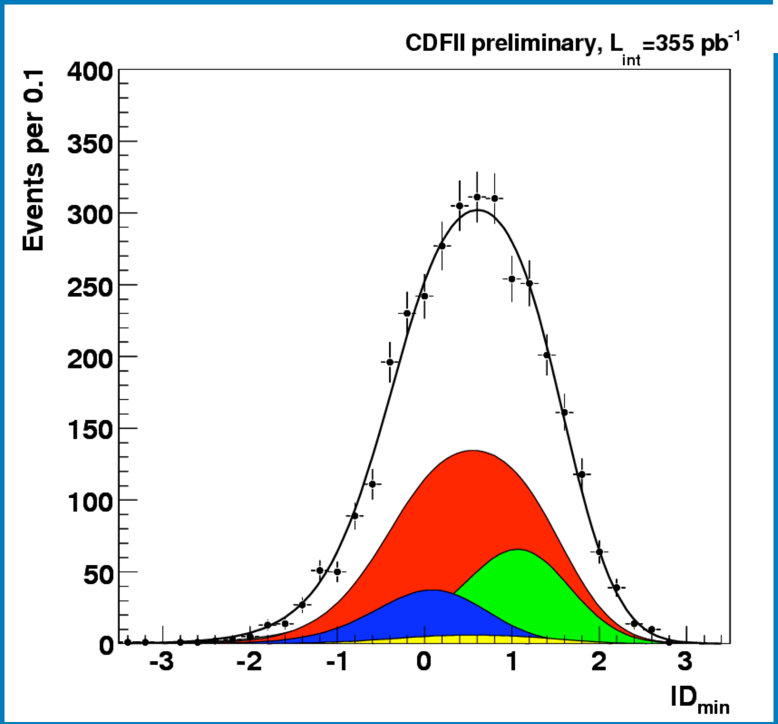
1.4σ K/π separation at $p > 2$ GeV/c

(≡ 60% of "perfect" separation)



$B \to h^+h^{-\prime}$: Fit Projections and A_{CP}





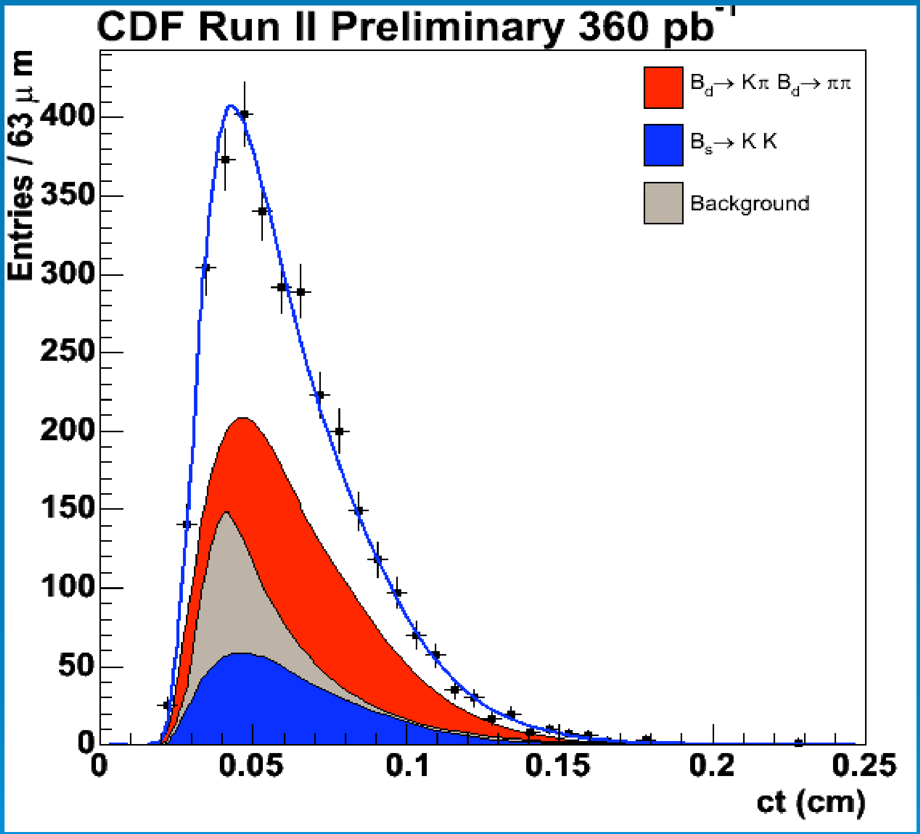
$$A_{CP} = \frac{N(\overline{B}^0 \to K^-\pi^+) - N(B^0 \to K^+\pi^-)}{N(\overline{B}^0 \to K^-\pi^+) + N(B^0 \to K^+\pi^-)} = -0.058 \pm 0.039\ (stat.) \pm 0.007\ (syst.)$$

CDF (355 pb^{-1})

- Result is consistent with B Factories
- Update on Decay Ratios expected in a near future

First $B_s \rightarrow K^+K^-$ Lifetime Measurement

- Measurement of B_s -> K^+K^- lifetime ($=\tau_L$) in 360pb[-1]
- Same technique described before (kin/PID ML unbinned fit): include Lifetime



Extraction of $\Delta\Gamma(CP)/\Gamma(CP)$:

- ~ 95% CP even, measures lifetime of "Light Bs"
- This measurement gives $c\tau_L = 1.53 \pm 0.18 \pm 0.02$ ps
- HFAG average gives weighted average: $(\tau_L^2 + \tau_H^2) / (\tau_L + \tau_H)$
- Extract $\Delta\Gamma_s(CP)$

(CDF:World best)

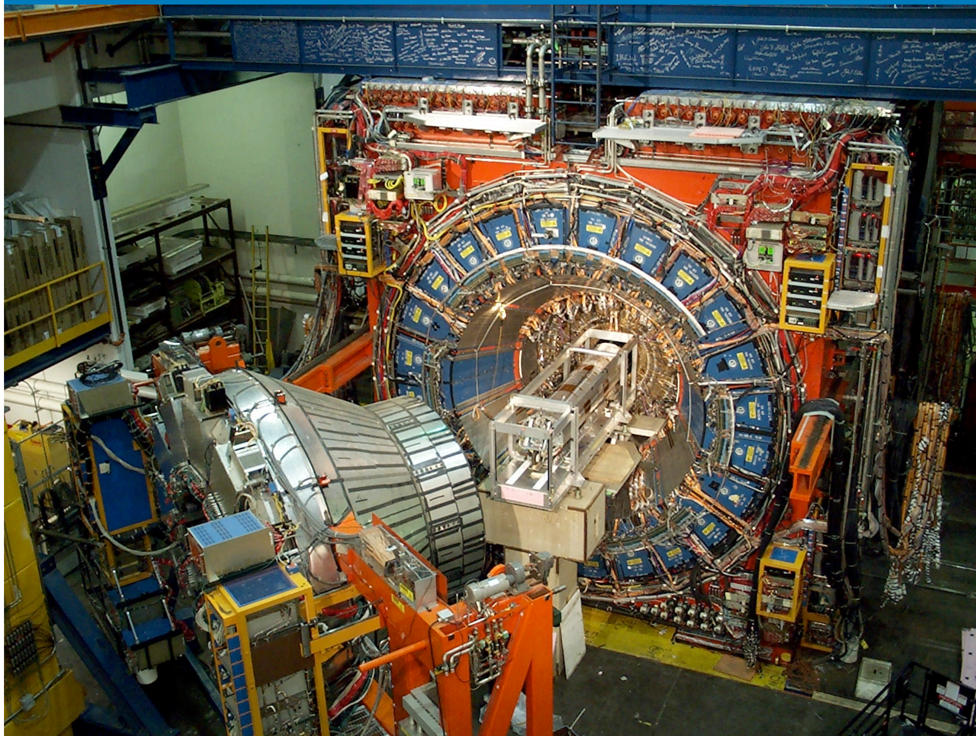
$$\Delta\Gamma_s/\Gamma_s = -0.080 \pm 0.23 \text{ (stat)} \pm 0.03 \text{ (syst)}$$

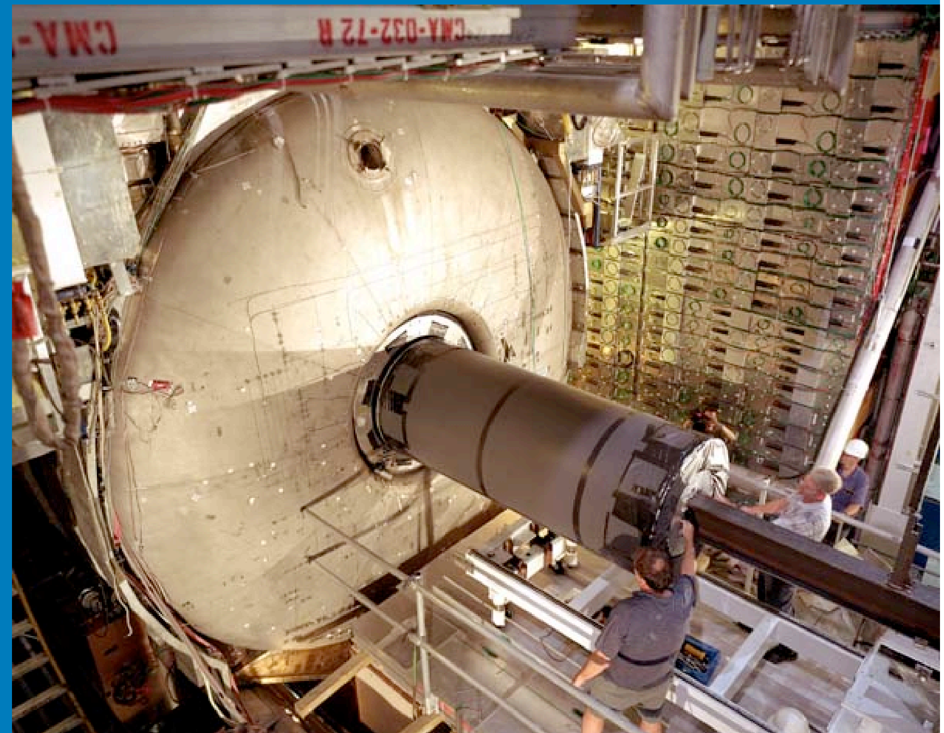
Summary

- Tevatron experiments are working great
- Several interesting analysis in the works with best world result
- Exciting times !
- Don't miss next talk: we will hear mixing results from Tevatron.

Backup Slides

CDF and D0 detectors





CDF:

- Excellent silicon vertex detector
- Good particle identification (K,π)
- Good momentum and mass resolutions

D0:

- Extended tracking and muon coverage
- Good electron identification
- New innermost-layer silicon detector will be installed in March

Summary of $\Delta\Gamma_s/\Gamma_s$ measurements

- CDF $B_s \rightarrow K^+K^-$: $-0.080 \pm 0.23 \pm 0.03$ (210 pb^{-1})
- D0 $B_s \rightarrow J/\psi\phi$: $0.24 \pm^{0.28}_{0.38} \pm^{0.03}_{0.04}$ (220 pb^{-1})
- CDF $B_s \rightarrow J/\psi\phi$: $0.65 \pm^{0.25}_{0.33} \pm 0.01$ (210 pb^{-1})

$B \to h^+h'^-$

Systematics

source	shift wrt central fi
mass scale	0.0022
mass resolution	0.0024
asymmetric momentum-p.d.f	0.0003
dE/dx	0.0050
input masses	0.0025
combinatorial background model	0.0019
p spectra of background	0.0005
MC statistics	0.0010
charge asymmetry	0.0022
$m_{\pi\pi} - p_{tot}$ non-factorizability	0.0018
TOTAL (sum in quadrature)	**0.0074**

Raw fractions

parameter	fraction	yield
$B^0 \to \pi^+\pi^-$ + c.c.	(0.132 ± 0.014)	313 ± 34
$B^0 \to K^+\pi^-$ + c.c.	(0.621 ± 0.017)	1475 ± 60
$A_{CP}(B^0 \to K^+\pi^-)$	(-0.066 ± 0.039)	–
$B_s^0 \to K^-\pi^+$ + c.c.	(0.027 ± 0.013)	64 ± 30
$B_s^0 \to K^+K^-$ + c.c.	(0.220 ± 0.016)	523 ± 41

CDF: $-0.058 \pm 0.039 \pm 0.007$

BaBar: $-0.13 \pm 0.03 \pm 0.009$

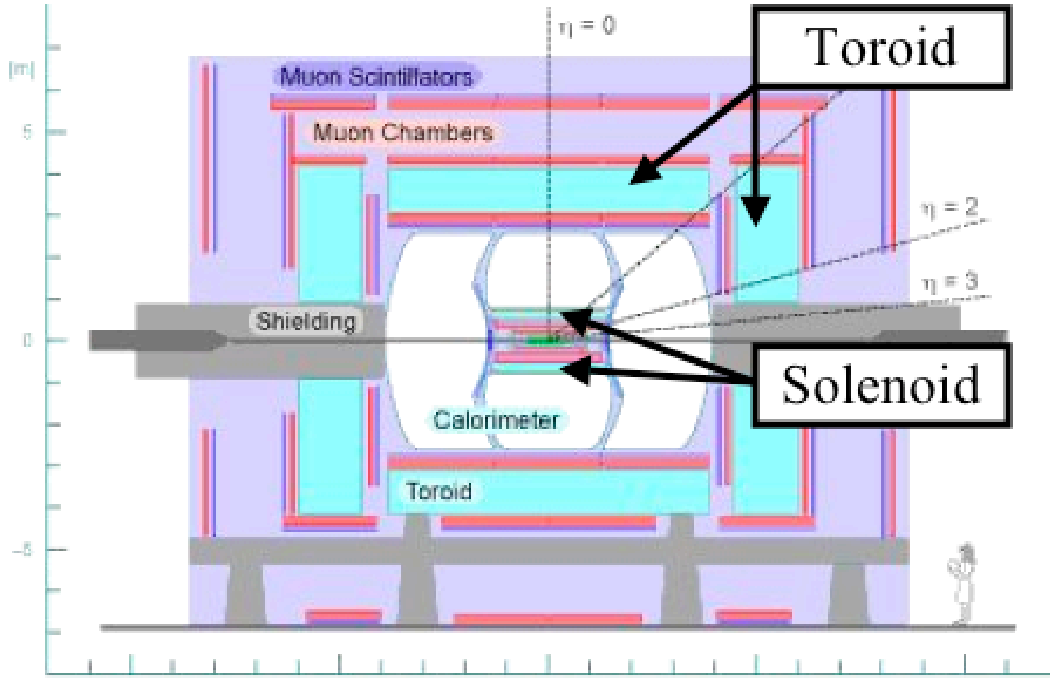
Belle: $-0.101 \pm 0.025 \pm 0.005$

D0: toroid and solenodi polarity

How?

Using independent spectrometers and reversing the polarities

Solenoid	Toroid
+	+
−	+
+	−
−	−



- Apparent dimuon charge asymmetry less than 0.006
- First order cancellation using polarity reversion

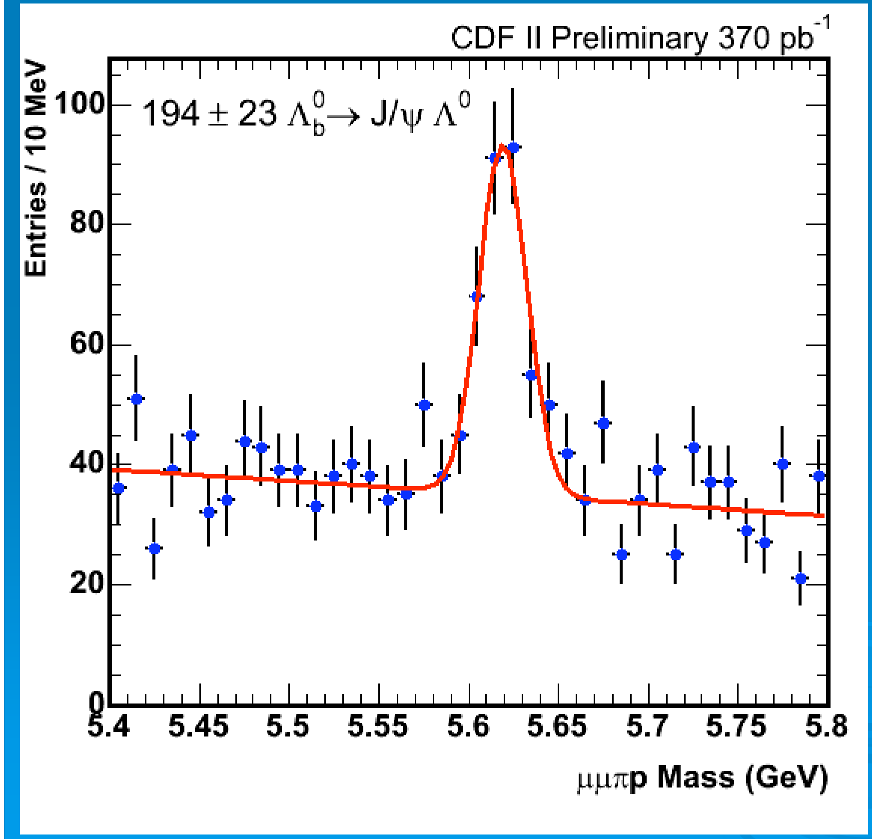
CP-violation parameter: systematics

A_{RAW} = - 0.0013 ± 0.0012 (stat) ± 0.0008 (syst)

Source of error	ΔA
detector	0.00015
Polarity exposure	0.00018
muon and $K^{\pm}$ decay	0.00068
dimuon cosmic rays	0.00010
prompt μ and cosmic μ	0.00001
Wrong charge sign	0.00015
punch-through	0.00001
Total	0.00074

Λ_b Lifetime

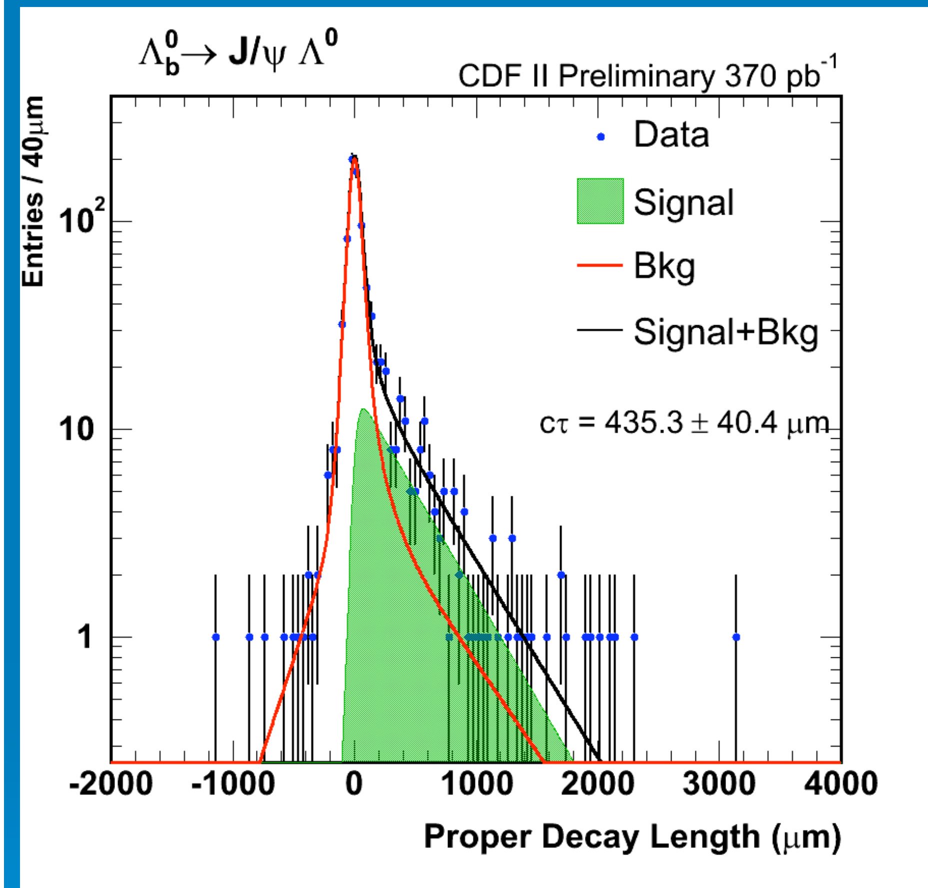
- Lifetime measurements are important tests of Heavy Quark Expansion (HQE)
- Long standing ~2σ effect between theory and experiment on $\tau(\Lambda_b)/\tau(B^0)$. Experiment on the low side



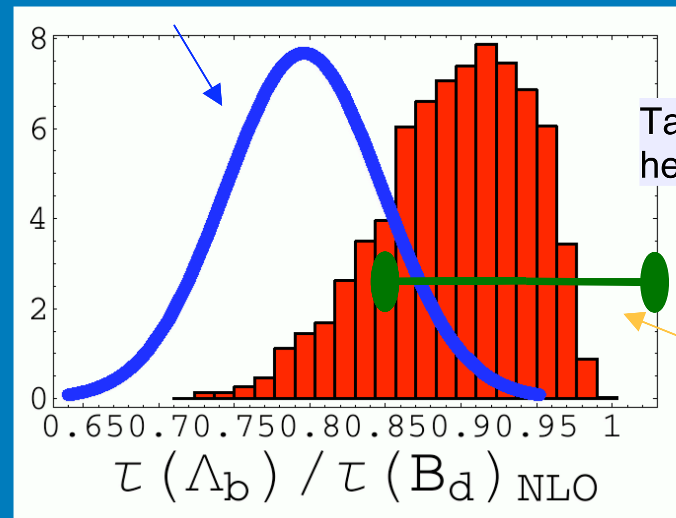
- CDF has measured the Λ_b lifetime using fully reconstructed

  $\Lambda_b \rightarrow J/\psi\ \Lambda$
- Better proper time resolution than semileptonic mode
- Combine with $\Lambda_c p$ channel, CDF has the largest fully reconstructed Λ_b sample in the world

Λ_b Lifetime



Experiment (world avg)



Tarantino, et al. hep-ph/0203089

CDF Result

CDF (370pb-1):

$$\tau(\Lambda_b) = 1.45^{+0.14}_{-0.13}(stat) \pm 0.02(syst)\, ps$$

- Active theoretical work to accommodate data
- CDF's new result sits in the theory preferred region
- Need more experimental inputs to resolve the issue
- Updated Results in a few weeks